

# **Attempt to Global Decoupling On Ramp**

*Yun Luo for the decoupling team*

- Candidate Correction Method for Ramp
- Skew Quadrupole Modulation
- Three Ramp Correction
- Coupling Phase Modulation
- Plan for Summer Shutdown and Next Run

## Candidate Method for Decoupling on Ramp

- Decoupling methods
  - Skew quadrupole scan
  - Beam response matrix
  - Local decoupling
  - $4 \times 4$  one-turn Map Correction
  - Feed forth and Feedback
- Characteristics of coupling on ramp
  - non-stop energy ramp
  - beam optics changes ( working points,  $\beta^*$ , COD )
  - coupling condition changes

**So FAST, ROBUST decoupling scheme and instrumentations needed!**

## T. Roser's Idea: Skew Quadrupole Modulation

It is logical change from scan to modulation.

To minimize the 1f peak of FFT of tune difference

- Merits of skew quadrupole modulation
  - > needn't push the tunes to linear resonance
  - > modulation strength small, beam is safe
  - > data taking faster than strength scan
- Hardware challenges

Robust Phase Lock Loop

Able to track the two tune modulations

## Hamiltonian Approach

- Approximation Theory based on Hamiltonian

$$Q1 = Q_{x,0} - \frac{\Delta}{2} + \frac{1}{2} \sqrt{\Delta^2 + |C^-|^2}, \quad Q2 = Q_{y,0} + \frac{\Delta}{2} - \frac{1}{2} \sqrt{\Delta^2 + |C^-|^2}$$

$$\Delta = (Q_{x,0} - Q_{y,0} - p), \quad C^- = \frac{1}{2\pi} \oint \sqrt{\beta_x \beta_y} \cdot k_s \cdot e^{i(\psi_x - \psi_y - (Q_{x,0} - Q_{y,0} - p) \frac{2\pi s}{L})} ds$$

$$(Q1 - Q2 - p) = \sqrt{\Delta^2 + |C^-|^2}$$

- With skew quadrupole modulation

assuming modulating skew Q:  $C^-_{modulating\_amp} \cdot \sin(2\pi f t + \phi_0)$

$$\begin{aligned}
 (Q2 - Q1)^2 = & \\
 |\Delta|^2 + |C^-_{residual}|^2 + \frac{1}{2} |C^-_{modulating\_amp}|^2 & \\
 + 2 |C^-_{residual}| \cdot |C^-_{modulating\_amp}| \cdot \cos \psi \cdot \sin(2\pi f t + \phi_0) - \frac{1}{2} |C^-_{modulating\_amp}|^2 \cos(2\pi \cdot 2f \cdot t + \phi_0)
 \end{aligned}$$

## Data Processing

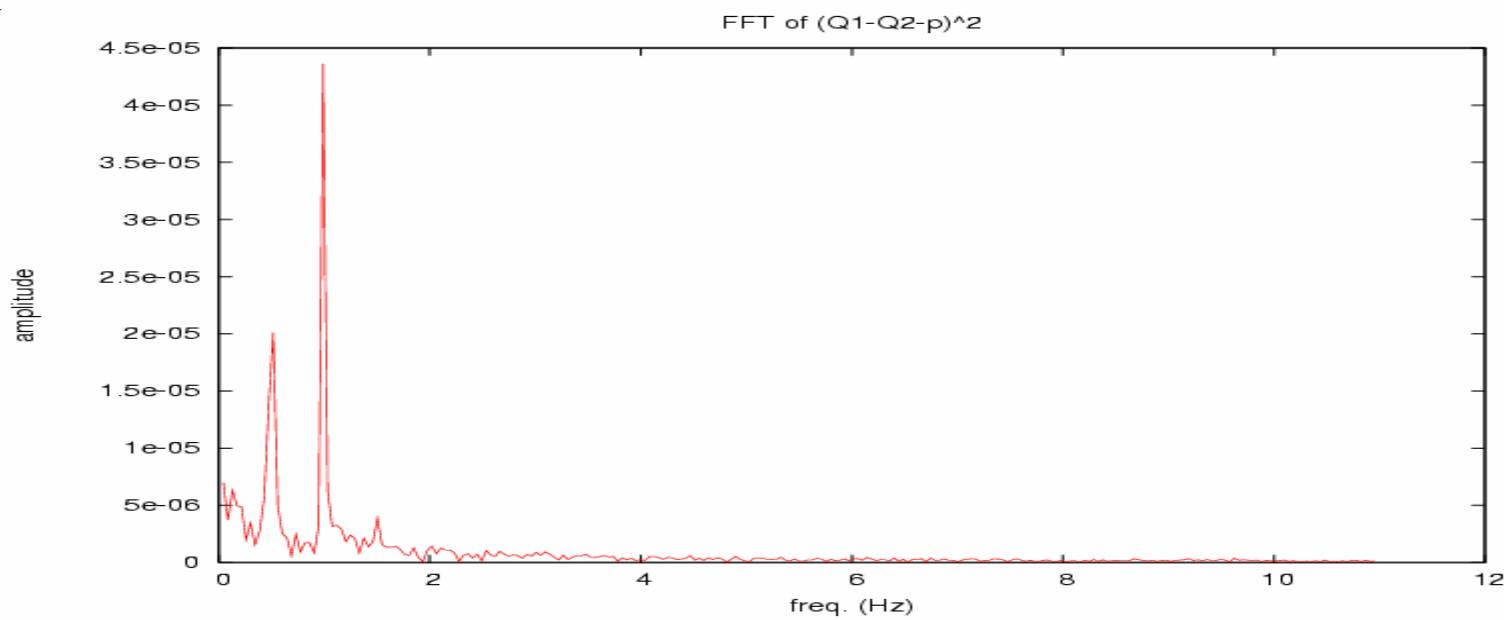
- FFT Technique

Projection Ratio:

$$\frac{|C^-_{residual}| \cdot |\cos \psi|}{|C^-_{modulating\_amp}|} = (peak_1/peak_2)/4$$

Projection sign:

$$\sum_{i=1}^N (q1 - q2)_i^2 \times i_{power\_sup\;ply}(t_i)$$



- Linear Regression

>Fit the data with function

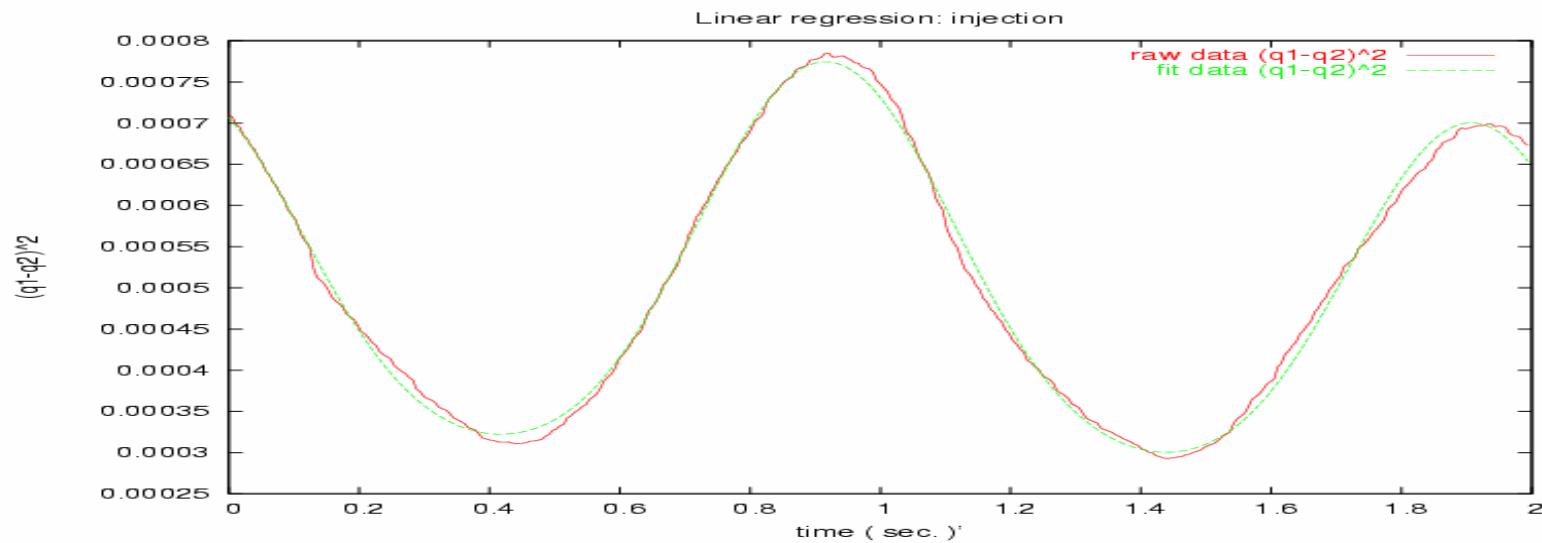
$$f(t_i) = A + B_1 \sin(2\pi f t_i) + B_2 \cos(2\pi f t_i) + C_1 \sin(4\pi f t_i) + C_2 \cos(4\pi f t_i) + E t_i + F t_i^2$$

>minimizing  $\chi^2$

$$\chi^2 = \sum_{i=1}^n [(q1 - q2)^2 t_i - f(t_i)]^2$$

> Projection ratio:  $\sqrt{B_1^2 + B_2^2} / \sqrt{C_1 + C_2}$

Projection sign:  $\sum_{i=1}^N (q1 - q2)_i^2 \times i_{power\_supply}(t_i)$

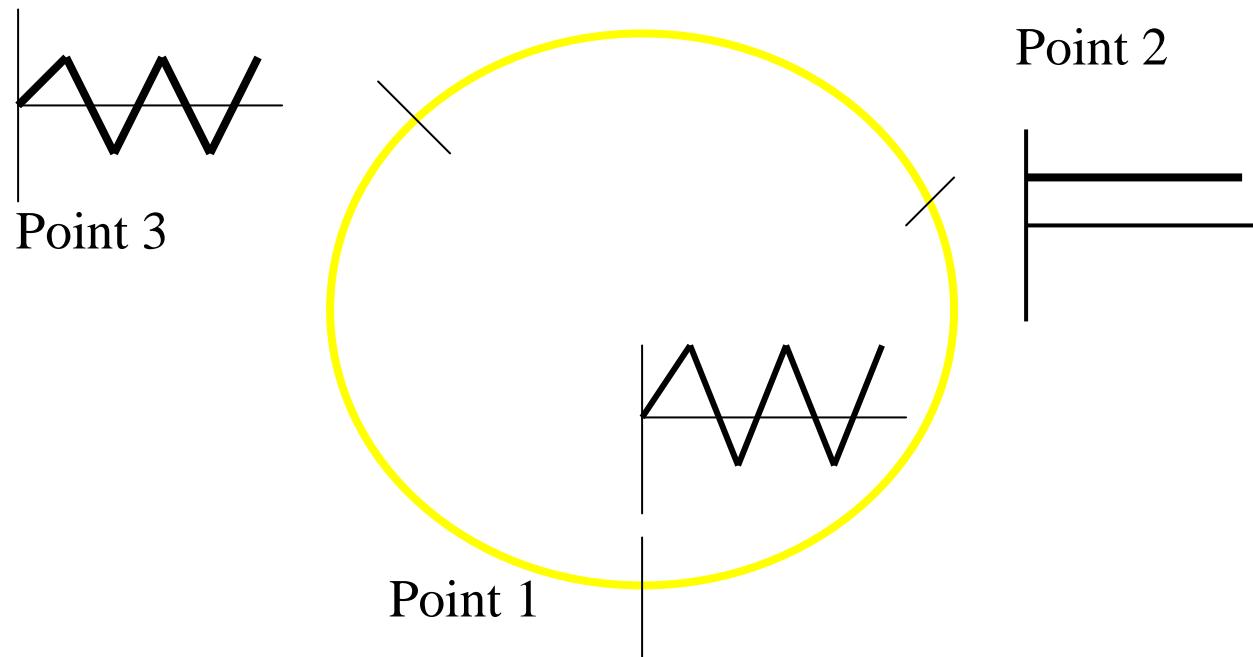


## Simulation Program

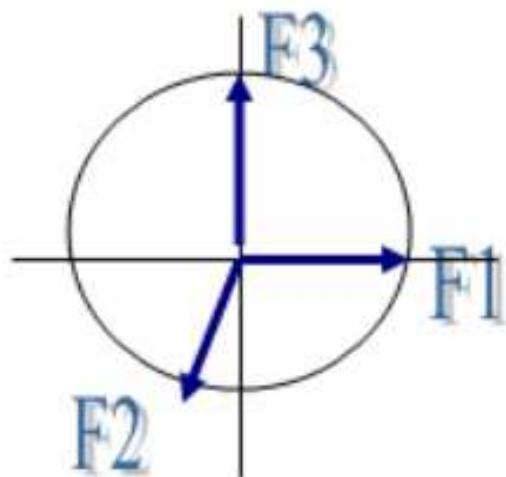
- Smooth accelerator model

$$z'' + \left(\frac{Q_z}{R}\right)^2 z = 0, \text{ where } z = x, y, \quad R = \frac{L}{2\pi}$$

- Tracking Parameters



## Example of Simulation



Assuming the residual coupling induced by F2: 0.005 (ks.dl)

### Step 1. MEASUREMENT

Modulation skewQ	Projection Ratio
F1( ksdl=0.005)	0.43
F2( ksdl=0.005)	0.91
F3( ksdl=0.005)	0.78

Step2: Correction (F1: 0.43\*0.005, F3: 0.78\*0.005 )

### Step3: Measurement after correction

Modulation skewQ	Projection Ratio
F1( ksdl=0.005)	0.04
F2( ksdl=0.005)	0.10
F3( ksdl=0.005)	0.07

*Iteration is welcome*

### Step4: repeat again:

#### Measurement after second correction

Modulation skewQ	Projection Ratio
F1( ksdl=0.005)	0.0032
F2( ksdl=0.005)	0.033
F3( ksdl=0.005)	0.0050

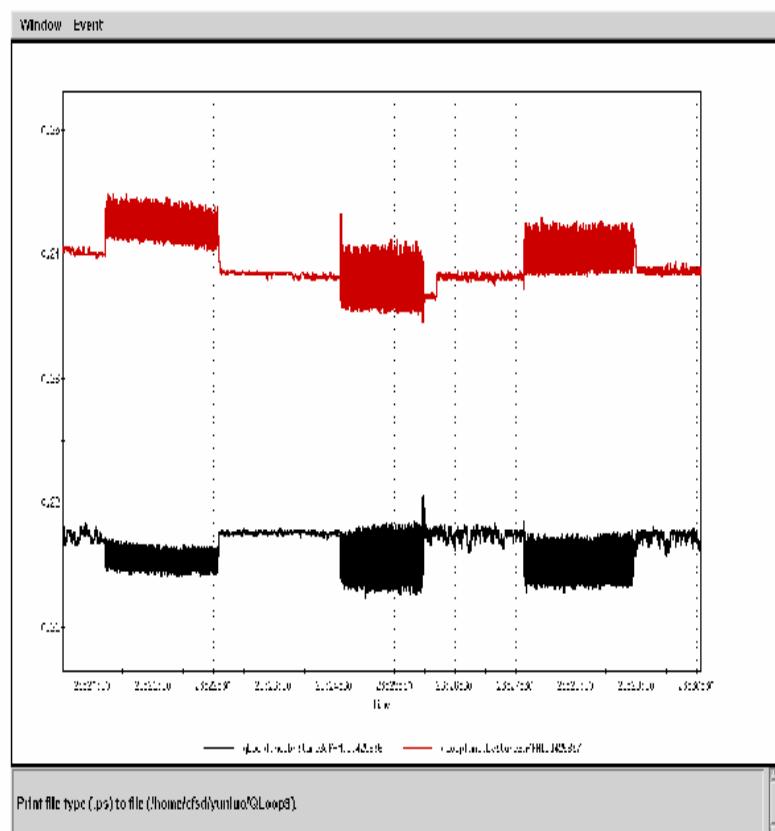
*For small coupling, use small modulation amplitude.*

## Beam Experiments

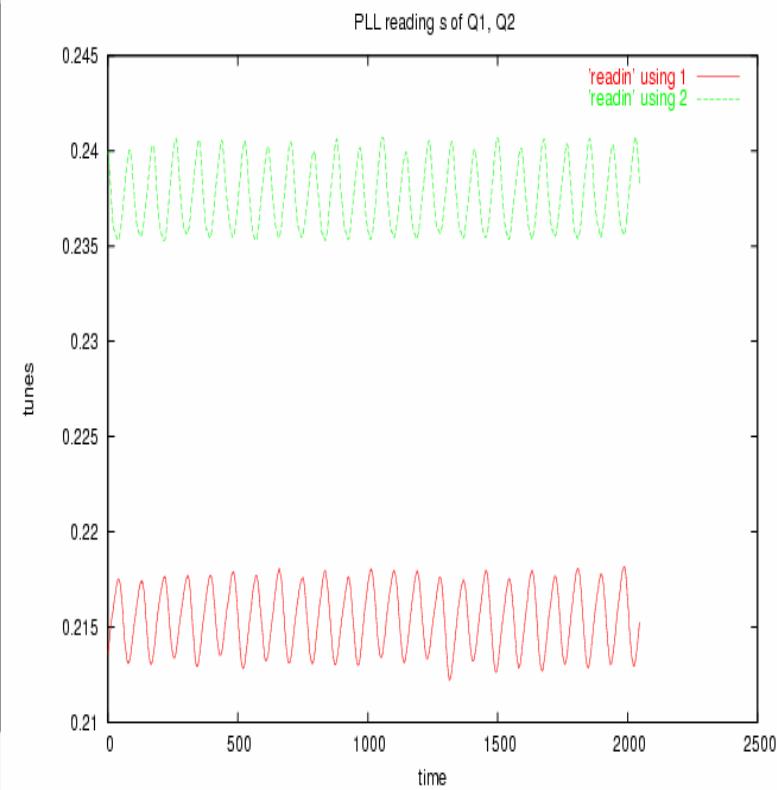
Session	Goal	Scheduled time (hrs.)	Observation
2004_Jan_6	injection	2.0	Two peaks seen
2004_Jan_13	injection	2.0	Measurement at injection
2004_Jan_27	ramp	2.0	PLL only one tune modulated Some data take at injection
2004_Feb_03	ramp	2.0	PLL lose locking data taken on ramp/ at store
2004_Feb_11	ramp	1.5	part data useful
2004_Feb_25	ramp	2.0	part data useful
2004_Mar_11	correction	0.5	test scheme at injection
2004_Mar_27	injection	1.5	test R. Lee's on-line program
2004_May_14	correction	0.5	test scheme at store

## Several Examples for Measurement / Correction

Zoom of PLL data

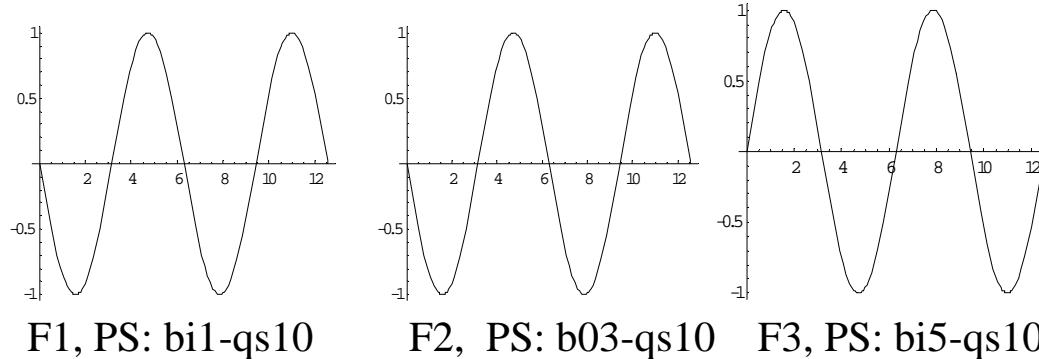


Zoom of PLL data



Jan\_13, 2004

Case 1: For the case with more coupling by adding SQ F3 strength by -0.0004



$C^-_{\text{modulating\_amp}}$	Direction:	$(109.5^\circ)$	$(49^\circ)$	$(169.7^\circ)$
Projection Ratio:		2.037	0.9181	3.45
Projection Sign:		-	+	-

$C^-_{\text{residual}}$ :

From ( F1, F2 )     $3.00/336.80^\circ$

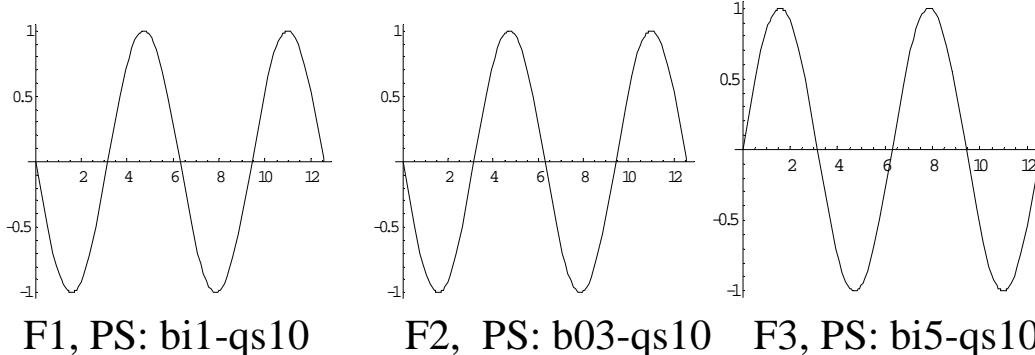
From ( F2, F3 )     $3.59/333.83^\circ \implies \frac{\Delta |C^-_{\text{residual}}|_{\max}}{|C^-_{\text{residual}}|} = 10.5\%$ ,  $\Delta |\psi|_{\max} = 5.5^\circ$

From ( F3, F1 )     $3.47/343.55^\circ$

- F3 -0.0004 at injection , comparable to 1.07A, direction  $349^\circ$

Jan 3, 2004

Case 2: For the case with more coupling by adding SQ F2 strength by 0.0004



$C^-_{modulating\_amp}$	Direction:	$(109.5^\circ)$	$(49^\circ)$	$(169.7^\circ)$
Projection Ratio:		0.6214	2.436	1.549
Projection Sign:		+	+	-

From ( F1, F2)       $2.52/33.75^\circ$

$$\text{From } (F2, F3) \quad 2.46/40.71^\circ \quad \Longrightarrow \quad \frac{\Delta |C^-_{residual}|_{\max}}{|C^-_{residual}|} = 4.7\%, \Delta |\psi|_{\max} = 3.99^\circ$$

From ( F3, F1)       $2.23/35.69^\circ$

- F2 0.0004 at injection , comparable to 1.07A, direction  $49^\circ$

March 11, 2004

first measurement: Average 1.5A / 99.8°

<b>condition</b>	<b>Amplitude(A)</b>	<b>Angle (deg.)</b>
(F1, F2)	1.596	107.49
(F2,F3)	1.367	101.41
(F1,F3)	1.629	97.79
(F2, F1F3)	1.417	102.95

Second measurement : Average 1.8 A / 106.45°

<b>condition</b>	<b>Projection ratio</b>	<b>Angle(deg.)</b>
(F1,F2)	1.609	64
(F2,F3)	2.31	100
(F1,F3)	1.18	123
(F1F3,F3)	1.647	109
(F1F3,F2)	2.06	93.8
(F1F3,F1)	1.434	146.8

- The answer : F1 strength  $\rightarrow + 0.0002$  at injection , 0.5 A / 109°

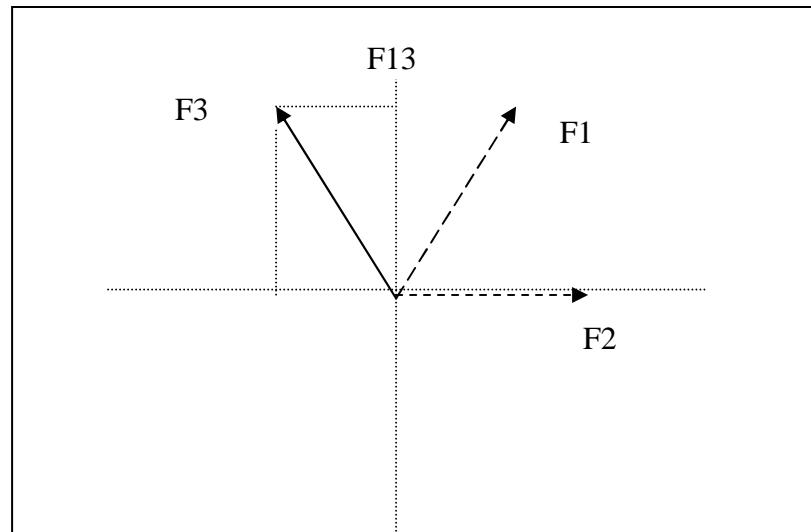
May 14, 2004

Machine condition	Modulation	Projections from FFT	Projections from FFT
F3: -0.0002	F2/1.0/0.5/60/10	1.37	1.48
	F1F3/1.0/0.5/60/10	2.53	2.45
F3: -0.0004	F2/1.0/0.5/60/10	0.32	0.32
	F1F3/1.0/0.5/60/10	0.22	0.19

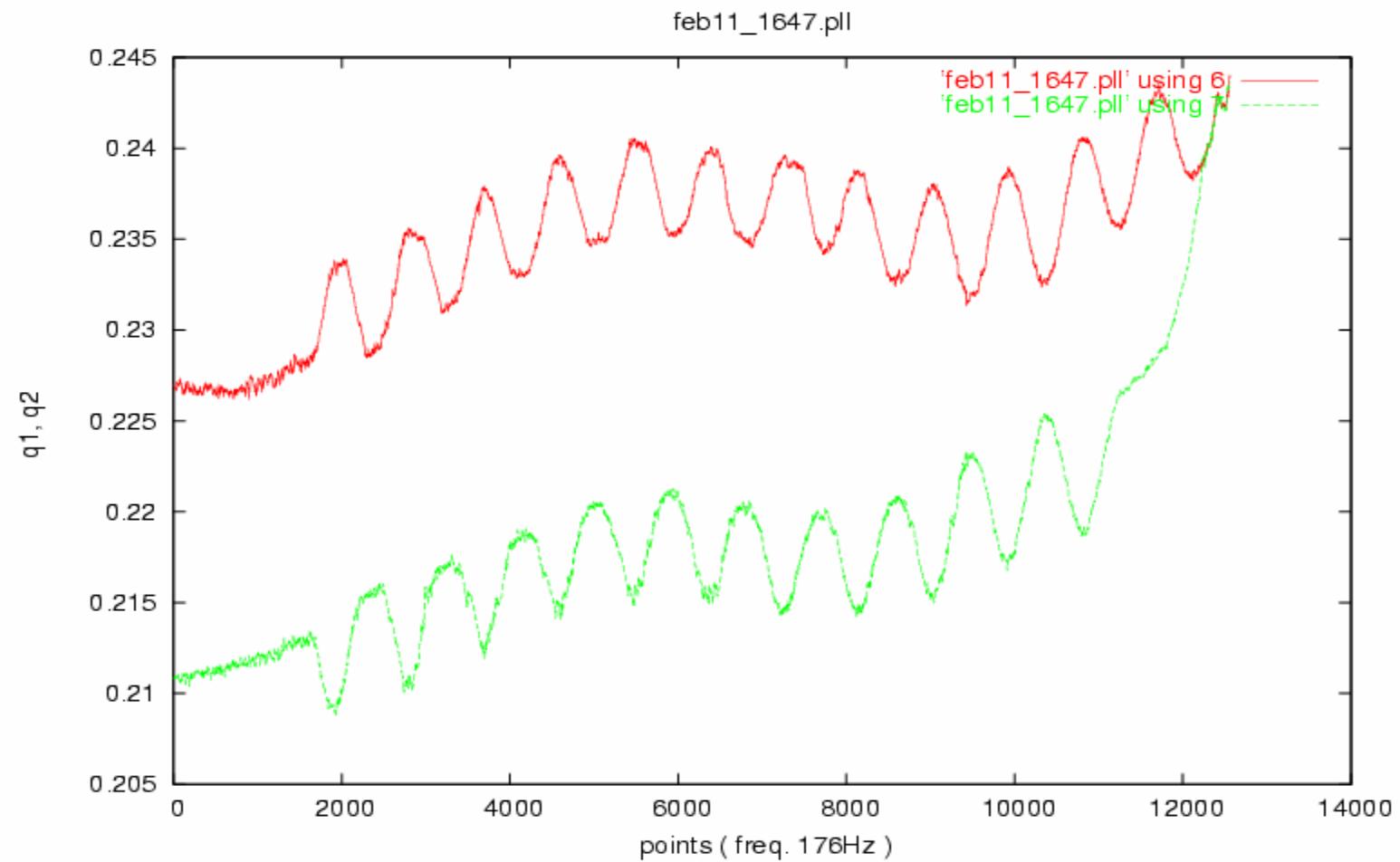
- F3 change  $\Delta F3=0.0002$  at store , about 2.2 A

	Meas.	Pred.
Projection on F2 change	~ 1.0A	1.1A
Projection on F13 change	~ 2.3 A	1.9A

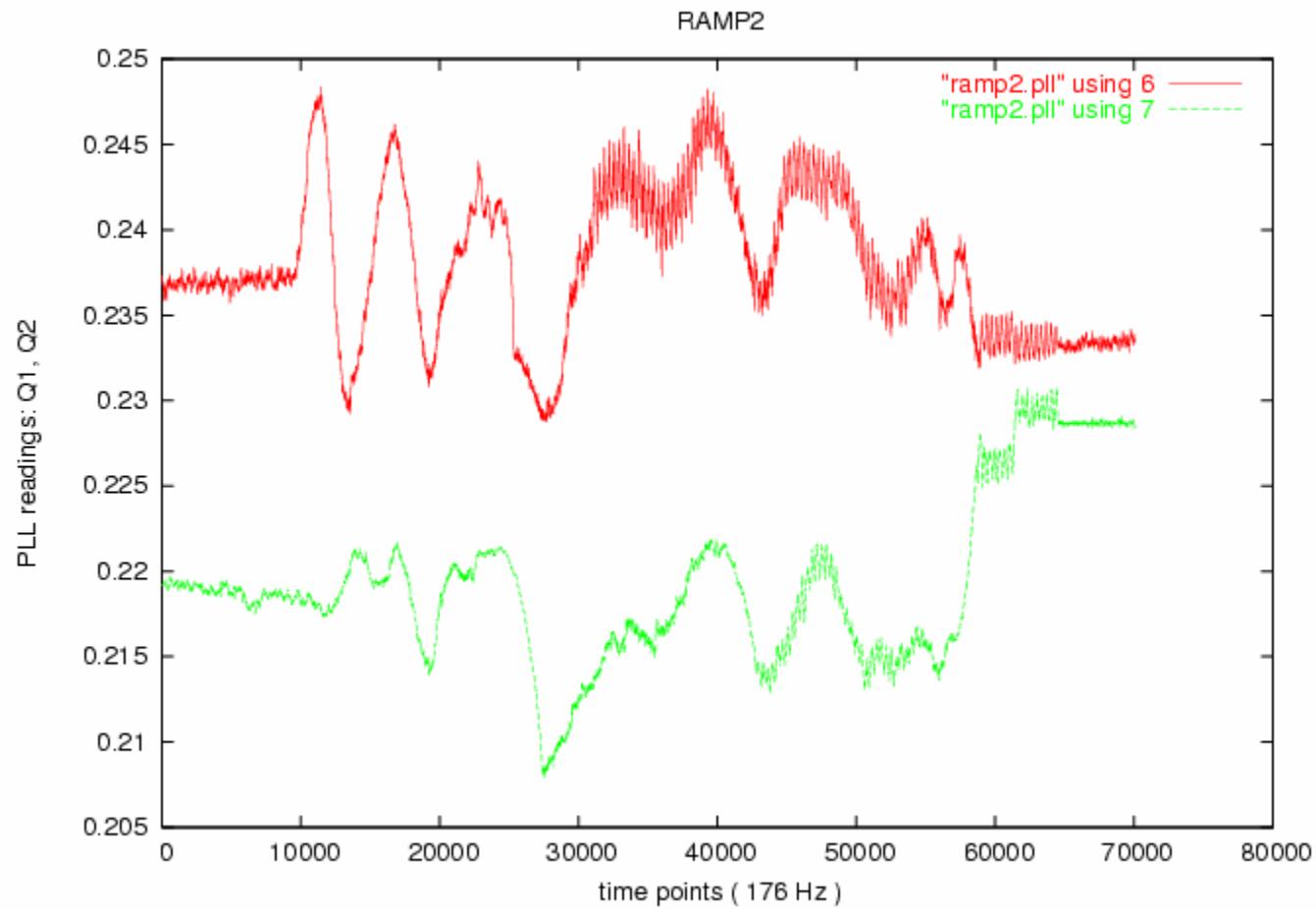
- Meas. and Pred. close



## Problems Encountered on Ramp



PLL lose lock



Tune modulation amplitudes not same

## Dejan's Idea: Three Ramp Coupling Correction Scheme

- Three variables needs three ramps

$$\begin{cases} {dq_1}^2 = \Delta^2 + |C_{residual}^- + C_{induced,1}^-|^2 \\ {dq_2}^2 = \Delta^2 + |C_{residual}^- + C_{induced,2}^-|^2 \\ {dq_3}^2 = \Delta^2 + |C_{residual}^- + C_{induced,3}^-|^2 \end{cases} \implies \Delta^2, C_{residual}^-$$

- Correction Examples

*April 13, 2004      day shift      first test      much better*

*May 8, 2004      evening shift      succeeded*

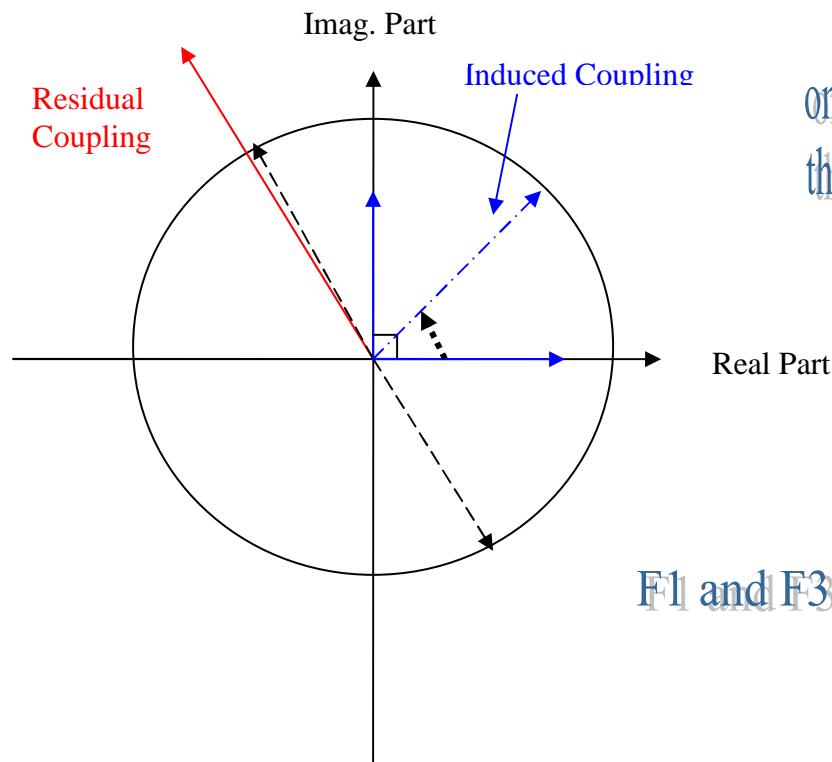
*Off-line data processing program ready*

- Comments

- > strongly model dependent method
- > can be used at injection and store , stones along the ramp .
- > better to use PLL data to get high resolution
- > expensive for ramp coupling correction

## Yun's Idea: Coupling Phase Modulation

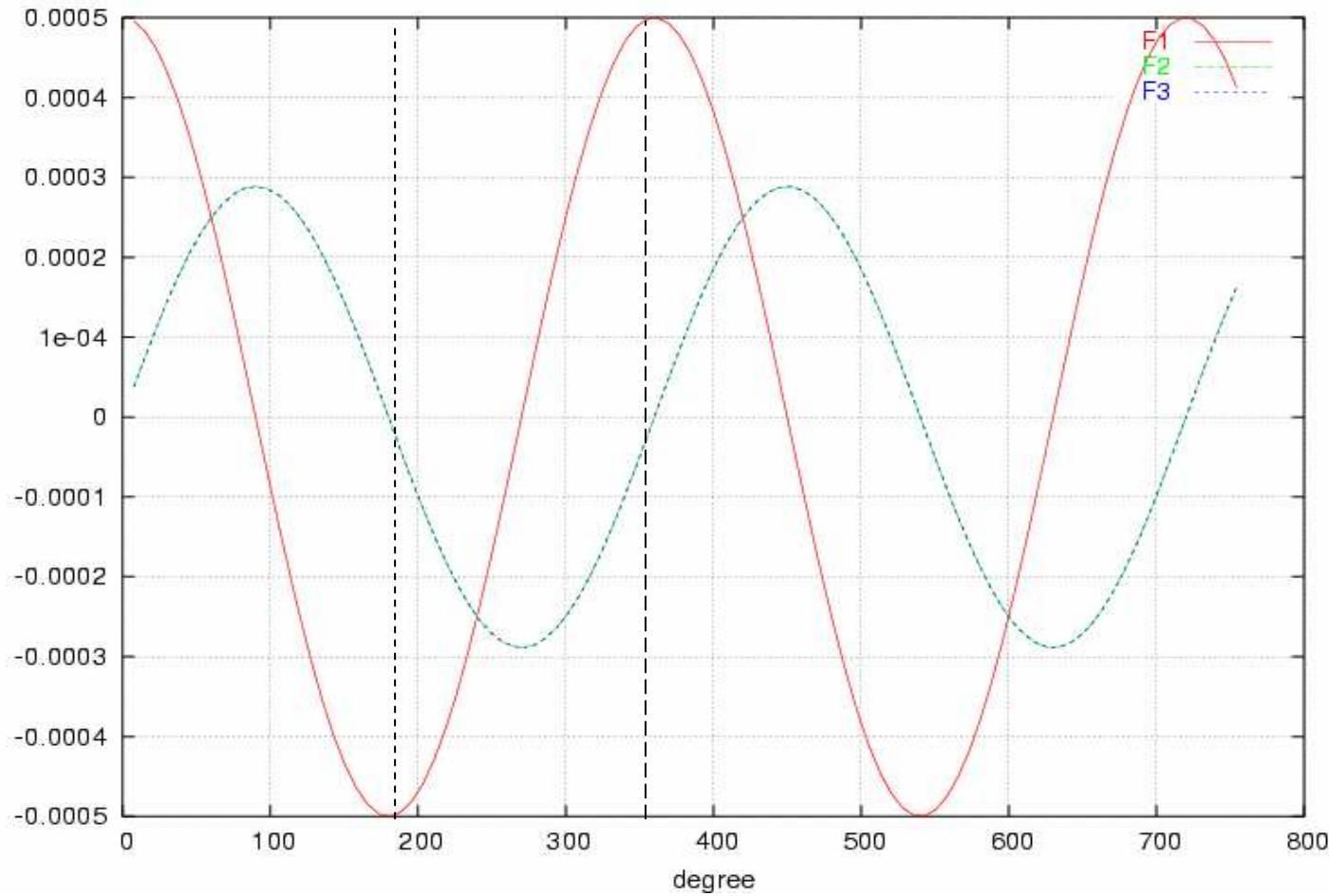
- What coupling phase modulation is



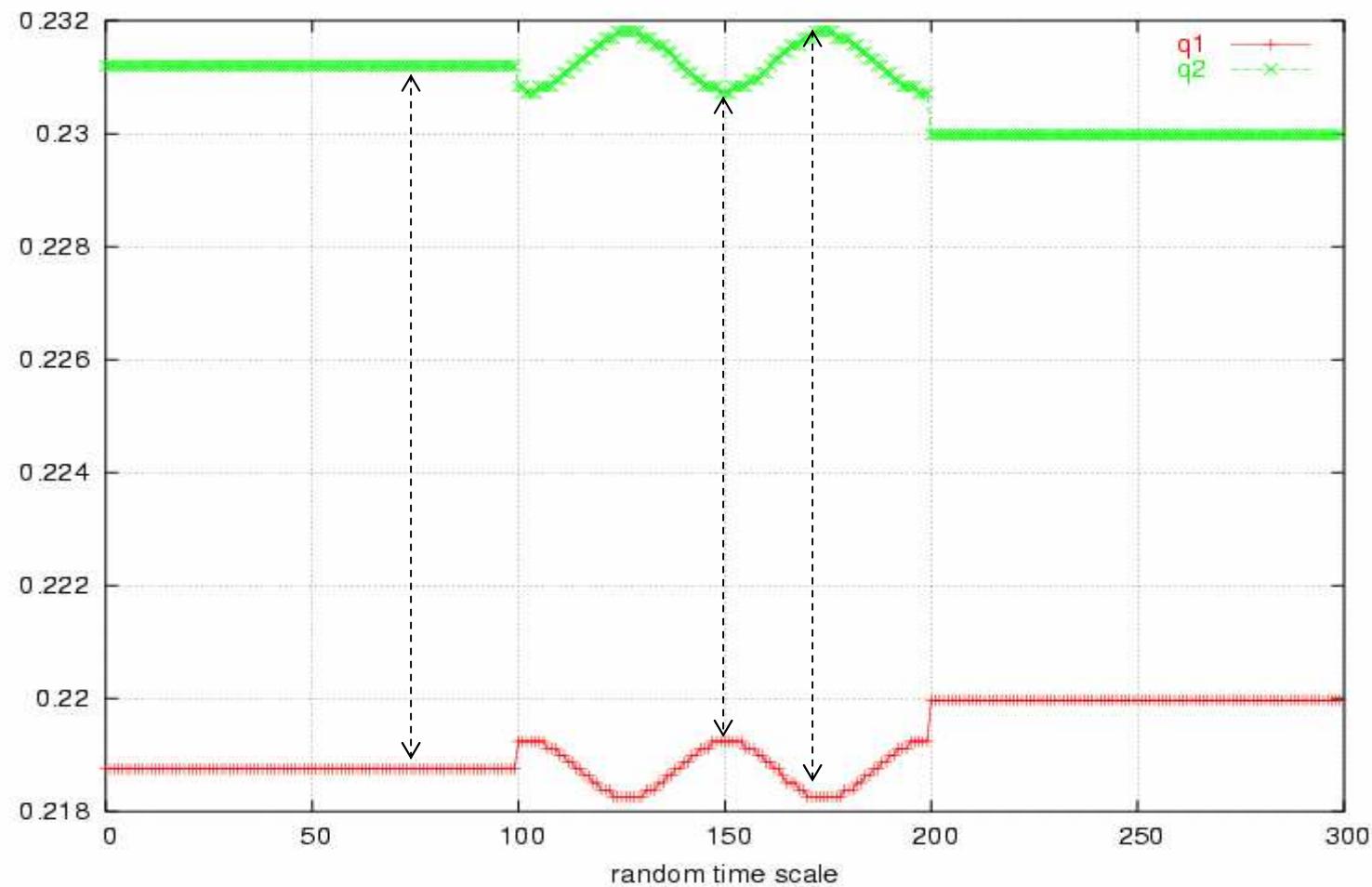
one modulation pattern:  $|C|\cos(2\pi f t)$   
the other modulation pattern:  $|C|\sin(2\pi f t)$

For RHIC  
F2 modulation:  $|C|\cos(2\pi f t)$   
F1 and F3 modulation same:  $(1/\sqrt{3}) * |C|\sin(2\pi f t)$

## Coupling Phase Modulation Simulations



## skewQ strengths



$q_2$  and  $q_1$  during modulation

## Formulae for coupling phase modulation

$$q_2 - q_1 = \sqrt{\Delta^2 + |C_{\text{residual}}^- + C_{\text{induced}}^-|^2}$$

$$dq^2 = (q_2 - q_1)^2 = \Delta^2 + |C_{\text{residual}}^- + C_{\text{induced}}^-|^2$$

$$C_{\text{induced}}^- = |C_{\text{mod,amp}}^-| \cdot e^{i2\pi ft}$$

$\implies$  when  $C_{\text{induced}}^-$  direction opposite to  $C_{\text{residual}}^-$ , dq is smallest

when  $C_{\text{induced}}^-$  direction same to  $C_{\text{residual}}^-$ , dq is largest

assuming  $|C_{\text{induced}}^-| = k |C_{\text{mod,amp}}^-|$ ,  $k > 0$ , then

$$dq^2|_{\max} = \Delta^2 + (k+1)^2 |C_{\text{mod,amp}}^-|$$

$$dq^2|_{\min} = \Delta^2 + (k+1)^2 |C_{\text{mod,amp}}^-| \implies k = \left( \frac{dq^2|_{\max} - dq^2|_0}{dq^2|_{\max} - dq^2|_{\min}} - \frac{1}{2} \right)^{-1}$$

$$dq^2|_0 = \Delta^2 + k^2 |C_{\text{mod,amp}}^-|$$

## Merits of Coupling Phase Modulation

- Modulation time short, 1-2 periods are ok.
- Modulation frequency could be fast or slow
- Data analysis very simple
- Only  $dq_{\max}$ ,  $dq_{\min}$ ,  $dq_0$  needed, doesn't care for the PLL detailed data  
Challenge to PLL on ramp much reduced.
- Much robust to noise and errors,  
for example, the two modulation families are not orthogonal,  
the two families' smodulation amplitude are not same...
- Less connection to optics

## Comparison of the Above Three Schemes

- Three ramp coupling correction
  - > simple, but expensive for ramp correction, the last choice
  - > connection to optics: more
- Coupling strength modulation ( ‘skew quadrupole modulation’ )
  - > data analysis complicated
  - > needs at least two not too short modulations
  - > PLL data quality important ( FFT / FIT )
  - > measurement and correction separately
  - > connection to optics: fair
- Coupling phase modulation
  - > more efficient and effective
  - > robust
  - > connection to optics: less

## **Work Plan for Shutdown Period**

- MCR on-line application program**

organize / implement / assist the writing  
coupling strength/phase modulations share one program  
completed before the start of next run

- Review the beam experiment data**

many data from beam experiments during last run  
looking-into again is very necessary, some puzzle unsolved

- Plan for next run**

## Plan for Next Run

- **One Goal**

Quickly apply skew quadrupole modulation correction on ramp  
in one month ?

- **Commissionings** in beginning of next run

test coupling correction at injection / store	2 weeks
test ramp coupling correction	2 weeks

- **Machine time support ( MUST)**

Modulation is very, very SAFE to beam, NEVER killed beam!

Parasitic measurements should be supported

One measurement is less than 1 min. , why not support it?